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349

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THE ATMOSPHERIC RAILWAY.

OBSERVATIONS

ON THE 9

REPORT

OF

LIEUT. COLONEL SIR FREDERICK SMITH, R.E. AND PROFESSOR BARLOW,

ON

THE ATMOSPHERIC RAILWAY.

ADDRESSED TO FRANCIS LOW, ESQ. CHAIRMAN OF THE DUBLIN AND
KINGSTOWN RAILWAY COMPANY,

BY

THOMAS F. BERGIN, M.R.I.A.

DUBLIN:
HODGES AND SMITH.
1843.

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ATMOSPHERIC RAILWAY.

FRANCIS LOW, ESQ.

CHAIRMAN OF THE DUBLIN AND KINGSTOWN
RAILWAY COMPANY.

MY DEAR SIR,

Looking on myself as being to a certain extent *particeps criminis* in having, in conjunction with the Treasurer of the Company, urged on the consideration of the Board the adoption of the "Atmospheric" system, as the best mode of working the Dalkey line, (the inclinations, and especially the curves, of which totally precluded the locomotive engine; and the best inquiries which I had been able to make showed the incompetency of horse-power to perform the anticipated amount of traffic,) I am desirous of placing on record the grounds of the convictions which have led me to this recommendation; and I feel the more desirous to do so at the present time, without waiting the result of experience, that I may satisfy you and the other Directors, that serious deliberation, and not any love of novelty or desire for experiment has been the actuating principle with both of us.

I have preferred putting these investigations in the form of an Examination of the Report of Sir Frederick Smith and Professor Barlow, as I thus have an opportunity of showing how and where I differ from these gentlemen, and the grounds of these differences. In the annexed observations, I have so fully gone into the leading principles of this system, and supplied the means by which those who feel sufficient interest in the subject may, with little trouble, extend their inquiries, that it is altogether unnecessary here to say anything more on the subject. I will not, however, let pass this opportunity of stating, that the results of my investigations have been, not only to *confirm* but considerably to *extend* those favourable views of the invention, which have actuated me in my recommendations to the Directors, and to convince me of the extreme importance of the "Atmospheric Railway."

I have the honor to be,
My Dear Sir,
Yours very faithfully,
T. F. BERGIN.

6th December, 1842.

OBSERVATIONS, &c.

OBSERVATIONS, &c.

THE investigation of the "Atmospheric Railway," (both experimental and theoretical,) by Sir Frederick Smith and Professor Barlow, the details of which are embodied in the report made by these gentlemen to the Earl of Ripon, President of the Board of Trade, and subsequently printed by order of Parliament, to whom the report had been presented by command of her Majesty, cannot be considered otherwise than as a document of great importance,—because, should the anticipations of the inventors and of the advocates of this novel mode of railway locomotion be at all borne out by the results, it must inevitably effect an almost incredible revolution in that newest gift of science,—mechanical travelling.

It is seldom that an invention, no matter what its pretensions, has the good fortune to be investigated in its earliest infancy by individuals so competent to the task; especially by a gentleman so long, intimately, and honorably connected with the science of the country as Professor Barlow ; and when we add the practical experience which Sir Frederick Smith must have acquired in his important office under the Board of Trade, I may well call the document an important one.

This Report, which is evidently the result of much laborious investigation, must be deemed absolutely conclusive as to the practicability of, and advantages to be derived from this invention; the words of the Report are decisive on these points,—" We consider the principle " of atmospheric propulsion to be established, " and that the economy of working increases " with the length and diameter of the tube;" and, in conclusion, they add,—" The atmos- " pheric principle seems to us well suited for " such a line as the projected extension from " Kingstown to Dalkey, &c."

Connected as I am with the Company who have had the honor,—some, perhaps, will for a short time say, the temerity,—to adopt this novel invention, the passages I have quoted from the Report might, and in all probability would, have been final and satisfactory to me, had I looked only to the application of the principle to that short line. But however important this extension may be to the interests of the Dublin and Kingstown Railway Company, I believe the success which I consider certain to attend this experiment, will be but the first impulse given to a power that, in its future progress, must be productive of most important and beneficial results, in which I trust my native country, *Ireland*, may yet largely participate.

The Directors of the Dublin and Kingstown Railway Company were the first public body, who took what may justly be considered the initiative step, in attempting to introduce into Ireland a comprehensive system of Railways, for the benefit of the nation, and under the exclusive control of the state. It is not necessary here to refer to the energy with which that first move was followed up, until it resulted in the appointment of the Irish Railway Commission, of which Professor Barlow was a member, and, of course, in conjunction with his colleagues, the late Mr. Drummond, Sir J. F. Burgoyne, Mr. Griffith, and Colonel Jones, a party to that invaluable Report, which has been so long and, I regret to say, so fruitlessly before the country. And why, it may be asked, is it that it is so? One of the reasons, and perhaps the strongest, is the cost of carrying out the magnificent plans of that Commission.

There are none to doubt the importance of such a system of railways as they recommended, nor the vast benefit which the country at large must derive therefrom. Differences of opinion may and do exist, as to whether Irish Railways should result from the enterprise of private individuals, united by the bond of their common as well as individual interest; or from the liberal policy of the government, acting for the universal benefit of the empire: but there is no difference as to the general principle.

When, therefore, a project is ushered into the world, promising, as does the "Atmospheric Railway," to remove so very large a proportion of this stumbling block of expense, it is surely a most important one; and there is no difficulty in understanding the anxiety with which the Report to the Right Honourable President of the Board of Trade was looked for, nor the attention with which it was necessarily read and considered on its appearance.

A careful perusal, however, of this document shows, I conceive, that some data in connection with the air-pump and with the space to be exhausted, have been omitted by the reporters: and that their method of estimating the leakage of the long valve relatively to that of the travelling piston, has led them to very erroneous conclusions as to the total amount of leakage; and, consequently, as to the economy of the system. The former omission is not very important, but the latter is extremely so; and I believe that had these data been taken into account by the reporters, their deductions would have been very much more in favour of this invention, than even those to which they have arrived.

The Report contains two classes of observations,—firstly, those which are the result of experiments instituted by the reporters, and of theoretical investigations founded on these experiments; and secondly, those which are, more properly speaking, matters of opinion only. These latter will be hereafter discussed; but the former, namely the experimental, and especially the theoretical investigations, sanctioned as they are by the very high authority of Professor Barlow, as a Mathematician and Experimental Philosopher, demand the earliest attention. It is with very great diffidence, indeed, that I differ from my respected friend, on a subject involving mathematical attainments, in which he is so rich, and to which I have no equal pretensions: nor would I have ventured to do so at all, were it not that, having observed the omission of data to which I have alluded, I found that introducing them into the theorems, would materially modify the conclusions of the reporters. The importance of the enquiry, and, I may add, the approbation of a scientific friend, the Rev. Doctor Robinson of Armagh, to whom I have communicated these "Observations," will, I hope, be sufficient excuse for me.

There are few of the calculations contained in the Appendix to the Report of Sir Frederick Smith and Professor Barlow, to which I have not applied the corrections I believe necessary. But it would too much extend my "observations," were I here to go over all of them; and after some consideration, I deem it my best course to produce new theorems, expressed in general terms;—to substitute the numerical values in a few of the most important or prominent cases set forth in the report;—and finally, to contrast, in tabular form, the numerical results given by the reporters with those which I have obtained.

Of the points investigated by the reporters, those to which I think it necessary to refer are stated in the following order:—

First—The expenditure of Engine power required to maintain any given amount of exhaustion already obtained in the working main.

Second—The power absorbed or expended in producing any desired vacuum in the working main: involving, in this step of the enquiry, the discharging or exhausting power of the air pump, and the waste of power by reason of the leakage of the whole apparatus.

Third—The separate determination of the part of the entire leakage, which being due to the travelling piston, is constant for the same degree of exhaustion, whatever length of main be in use; and of the part which is variable being due to the long valve and joints, and consequently dependent on the length of main.

Before entering on the examination of these points, it is desirable to refer to one matter, in which there is in the report some apparent confusion, and which, if not corrected, is almost certain to lead to misapprehension. I allude to the value of the unit of horse-power used by the reporters. Throughout the report all the numerical results in horse-power are given on the assumption that each such horse-power was equivalent to 33,000 lbs. raised one foot in a minute, although towards the end (at page 13), the reporters say, "We have already stated that the "unit of our horse-power is 33,000 lbs. raised one "foot in a minute, and that our numbers must "not be confounded with the nominal power of "the engine, as estimated in the usual way by "the diameter of the cylinder and the length "of stroke. Every such nominal horse-power "may be considered as capable of raising 58,000 "lbs. one foot in a minute, and, after deduction "for the friction of the air pumps, of still ex-"hibiting at the working point, 52,000 lbs; "*consequently, all our numbers require to be* "*reduced in the proportion of* 52 *to* 33, *to ob-*"*tain from them the nominal horse-power requi-*"*site for producing any of the above results.*"*

If it be asked, what consequence which of these units is adopted, they being but *different modes of expression for the same amount of*

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* I have taken the liberty of putting these latter words in italics. They are not so in the original.

power? the reply is, that the *nominal* horse-power is not only that exclusively recognised and used by engineers, for the *performance* of engines, but it is also the *commercial* unit by which the *cost* of engines is regulated. And hence it is important to direct particular attention to the reduction of the reporter's numbers: and the more so, because in the report, at page 8, much stress is laid on what may be called the converse; namely, that by using the *subsequently admitted unrecognized* unit, the engine at Wormwood Scrubs, which commercially is of 16 horse-power, would, according to the reporters, really be of 25 or 26 horse-power; and consequently, to erect such an engine, with the air-pump, would cost about £1,000, instead of £640 or thereabouts. When I come to treat of the engine power necessary for long lines, it will be obvious how very erroneous an impression, as to the amount of capital to be expended, is conveyed (however unintentionally,) by the reporter's having adopted a measure of horse-power which is not recognized by engine makers. It may also be desirable to explain the probable source of this error, as it is generally understood that steam engine horse-power is a certain definite quantity of work done, such as could be performed by a horse, whereas in fact it is a conventional expression for the dimensions of a steam engine.

James Watt originally estimated the unit of horse power as equivalent to 33,000 lbs. raised one foot high each minute: and on this estimate he established the dimensions and proportions of the several parts of an engine; so that, notwithstanding the various losses and expenditures of force, which he considered the steam to sustain between the boiler and the working point, there should still remain this amount of *available* power or *useful effect.* And from comparison of the dimensions of his engines with the above assumed effect, it would appear he considered that about four-tenths of the *original* power of the steam was thus absorbed: and this is the proportion of loss assumed, in the method for determining the horse power of steam engines used by the reporters, which is the same as that generally given by writers on the subject.

The steam engine indicator, (an instrument which, though early proposed, I believe, by Watt himself, has only recently come into general use,) has incontrovertibly proved that the *useful effect* had been very much under estimated. Besides, since Watts' time the steam engine has received, and is still receiving, most important improvements: the result is, as every person practically familiar with the subject perfectly well knows, that the quantity of water evaporated to produce the *useful effect*, which Watt estimated at 33,000 lbs. raised one foot each minute, does in fact produce at the working point an effect more nearly represented by 55 to 60,000 lbs. raised the same space in the same time; or, making ample deduction for the condenser and feed-pumps, friction, &c. and, in the present case, for the friction of the exhausting pump, there remains, as already quoted from the report, an available power of 52,000 lbs. or upwards.

Engine makers have not thought it expedient to change the horse-power dimensions of their engines, such having by use become the *commercial* standard for price ; but they know very well, and so does the purchaser know (or he ought to know) that by (say) a fifty horse engine, is meant one which, by using the ordinary formula of calculation, will give the power named ; but which, by the consumption of a given quantity of fuel, raises for each such horse-power not

33,000lbs. but 55,000 to 60,000lbs. the work of the pumps, friction, &c. included; such being the actual work performed by modern well constructed steam engines.

I now proceed to the examination of those parts of the report I have named.

First. The expenditure of Engine power necessary to maintain any given amount of exhaustion already obtained in the working main.

The mode of experimenting on this point adopted by the reporters, as stated in the printed report, was as follows:—The end of the main furthest from the air-pump was closed, by inserting therein the travelling piston, which, by means of the carriage brake, was prevented moving. The main was then exhausted, till the mercury in the vacuum gauge stood at any desired height.

If the air pump had then been stopped, this column of mercury would have fallen, in consequence of the leakage of the apparatus; but it was kept working at such a rate, as maintained the mercury in the gauge at as nearly an uniform height as was practicable: the number of strokes per minute, necessary for this purpose, was carefully noted, and was considered as a measure of the leakage. The same was repeated for various degrees of exhaustion, from 15 inches to 22 and 23½ inches of mercury.

"Having thus determined the number of "strokes requisite to support different degrees of "vacuum," they proceeded "to compute the "mean pressure per inch on the air-pump piston, "when working against these different vacuums."

The mode of calculation is then given, together with the resulting mathematical general expression; from which, by a simple arithmetical process, the mean pressure on the piston, at any degree of exhaustion of the main, is easily obtained; from whence is readily deduced the *nominal* horse-power requisite. In this last step, however, they use the unrecognised unit of horse-power, to which I have just referred. It is to be presumed, that the previous pages of the report had been printed off, before the reporters discovered this. Otherwise, they surely would have made the proper corrections; instead of leaving, as they have done, the consequent excessive expressions of power standing throughout the report, merely stating the necessity of correction in a remote paragraph; and thus leaving on the minds of a large number of readers an impression very different from the fact. At all events, it is here necessary to reduce their numbers of horse-power, as they themselves direct; consequently, their 20 horse-power should be read 12.7; their

12.4 horses as 7.9; and so for all other numbers of horse-power used throughout the report. This subject I have already entered into at some length, but I thought it desirable again to refer to it here, as a convenient place to illustrate, by an example, the bearing of my former remarks on the several calculations throughout the report.

The manner of experimenting which I have quoted is unobjectionable; but in the calculations founded on these experiments, I observe the omission of data before referred to.

A slight examination of the process of computation, which is given in some detail, shews that the reporters considered the air-pump as being *absolutely perfect;* that is, that its valves opened without resistance, and that there was no space whatever left between the piston and the pump cover, at the end of the stroke; or, in other words, that when the piston receded from the pump cover, and until the valve communicating with the receiver or main to be exhausted, opened, there was an *absolute vacuum.* From such an imaginary instrument, they compute the mean pressure on the air-pump piston, corresponding to the height of the column of mercury in the vacuum gauge; and taking this as the measure of effect, they calculate back, to find the power which should have been expended by the steam engine, to overcome this calculated resistance, using Watt's unit of horse power; and then applying these deductions from a *theoretical* apparatus, to the actual pump in use at Wormwood Scrubs, which it will presently be seen does not fulfil any of the assumed conditions; and without enquiring how far this pump is from the perfection calculated on, and consequently, without making any allowance whatever for its defects, they at once charge all the strokes which it had to make more than would have been required from a *perfect* instrument, as so much power inevitably wasted by the invention; and from this obviously incorrect estimate, they go on to calculate the expense of working, and the length of main which an engine can exhaust.

Now what is the fact? The air-pump at Wormwood Scrubs is so far from fulfilling the conditions of perfection assumed by the reporters, that its valves require a pressure or force to open them, amounting on a mean of several experiments, to 1.263 inches of mercury, or more than six-tenths of a lb. per square inch of piston surface; and the whole capacity of the pump being 16.45 cubic feet, the space traversed by the piston during the stroke is only 14.373 cubic feet,* leaving at each end a waste space of 1.038 cubic feet, or about one-sixteenth of the whole capacity; which spaces must at all times, during the working of the pump, remain filled with air of density *greater* than that of the atmosphere by the force required to open the valves; and which dense air, when the piston recedes from the cover, expands and in part occupies the space which ought to be filled with air from the main, and be forced out at the return stroke; thereby diminishing the exhausting power of the pump. The actual amount of loss thus sustained will be subsequently calculated; but it may be well familiarly to illustrate its effect, by assuming a very extreme case. Suppose this waste space amounted to one half the entire capacity of the pump, it is clear the pump must always have within it, the bulk of this half-pump-space of air rather denser than the atmosphere; that, when the piston recedes to the farthest end of the pump barrel, this dense air will have expanded into double its former volume, and be reduced to half its former density. Now it is clear that no air from the receiver or main could possibly pass into the pump, unless it were of still greater density, or *more* than half as dense as the atmosphere; consequently, in such an apparatus, with the vacuum guage at about fifteen inches, the pump might work *ad infinitum* without removing a single bubble from the main; yet, on the mode of calculation used by the reporters, the whole power of the engine, no matter how great, would *seem* to be just able to surmount the leakage. The amount of this error is not immaterial, even with the lower degrees of exhaustion; but in the higher degrees, it swells to considerable magnitude. As, however, it can without difficulty be almost totally obviated in an air-pump properly constructed, I should have contented myself by merely noticing its existence, were it not that I have other and more serious objections to the reporters' deductions; and as my object is to point *where* and *how* I differ from these deductions, it is necessary I should include all I have observed. But to return to the report; I have recalculated the mean pressures for each inch of exhaustion, from 12 inches to 25.75 inches, taking into account the data omitted by the reporters, (see note 1,) and give my results contrasted with theirs in the following table.

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* On reference to the dimensions of the air pump, as given in the report, page 7, it appears the reporters took for its capacity the area of the piston, multiplied by the length of the stroke; which gives the above quantity, say 14.4 feet, and which is used as its capacity in the calculations in page 8; whence I must infer that Sir Frederick Smith and Mr. Barlow omitted to ascertain the fact, as to whether the piston did or did not move to the end of the cylinder, as if they were acquainted with the fact, I can scarcely suppose they would have considered it so unimportant, as to have omitted it from their calculations.

The dimensions which I have used, have been obtained by actual measurements.

TABLE I.

Number.	Inches of mercury as shewn in Vacuum Gauge.	Effective mean pressure in lbs. per square inch on air pump piston.		Difference of pressure by reporters' formula, in lbs. per square inch of piston surface, resulting from their having omitted the imperfections of the pump.
		By reporters' formula.	By present formula.	
1	11	4.34	4.75	— 0.41
2	12	4.59	4.87	— 0.28
3	13	4.87	5.02	— 0.25
4	14	5.03	5.09	— 0.06
5	15	5.19	5.13	+ 0.06
6	16	5.33	5.12	+ 0.21
7	17	5.43	5.06	+ 0.37
8	18	5.49	4.94	+ 0.55
9	19	5.51	4.77	+ 0.74
10	20	5.49	4.53	+ 0.96
11	21	5.41	4.21	+ 1.20
12	22	5.29	3.81	+ 1.48
13	23	5.09	3.30	+ 1.79
14	23½	4.97	2.93	+ 2.04
15	24	4.83	2.66	+ 2.17
16	25¾	4.15	1.10	+ 3.05

This table exhibits the amount of the imperfections of the pump omitted in the report; and although I shall, to a certain extent, be anticipating a succeeding part of this enquiry, it may not be uninteresting to carry this tabulated exposition a step further; by shewing the horse-power required, according to the reporters' formula, to maintain a steady exhaustion, in contrast with the true *nominal* or *commercial* horse-power which I have deduced; thus exhibiting the power expended, in terms of the *generally understood* horse-power.

From the printed report I take four cases as a sufficient exemplification, viz., at 16, 18, 21, and 23½ inches of vacuum, which were observed to be respectively maintained by 16, 18, 29½, and 42 double strokes per minute.

TABLE II.

No. in Table I.	Inches of Mercury in Vacuum gauge.	Double Strokes per minute to maintain exhaustion. (See Report page 7.)	NOMINAL HORSE POWER,		
			By Reporters' formula and their divisor of 33.000	By present formula, with divisor of 52.000, and corrected mean pressure from Tab. I, being the true Horse power.	Differences in Excess by Reporters' Formula and Horse-power unit.
6	16	16	10.7	6.5	4.2
8	18	18	12.4	7.1	5.3
11	21	29.5*	20.	9.9	10.1
14	23.5	42	26.2	9.8	16.4

* In the printed report, page 7, it is stated that 29.5 double strokes per minute, with a mean pressure of 5.41 lbs. makes the engine of twenty of their horses'-power, that is, 12.7 of the usual value, from which the above numbers in the two last columns are calculated.

From these tables it is obvious, admitting as correct the mode of calculation I have adopted, of which I believe there cannot be any doubt, that the printed report does not in any case give the correct mean pressure on the air-pump piston, and for the higher degrees of exhaustion is very much in excess; as also are the reporters' estimates of horse-power necessary to supply leakage—rising, in the four cases which I have taken, from an excess of 63 per cent. to nearly three-fold.

The differences in excess shown in the last column of this table (2,) are rather serious; and the more so, if it be kept in mind, that by the reporters' mode of separating the *variable* from the *constant* leakage, much the greater part of the whole amount is, in their statements, necessarily thrown into the former; and as these results are deduced from experiments on only half a mile of main, they would become very important indeed when extended to lengths of some miles; for instance, in the report, page 10, it is stated, that with a vacuum of 18 inches and a three-mile main, the whole leakage, (the exhaustion having been previously produced,) would amount to 62 horse-power, of which 2.48 would be the constant part due to the piston, and 59.52 the variable part dependent on the long valve and joints. Or, extending the same mode of calculation to lengths of five miles, which I believe will be found to be about the most convenient as well as advantageous distance between the pumping engines; and agreeing with the reporters, that the "leakage power" is that which ought to be provided, in addition to the discharging power; the maintaining power for 18 inches of exhaustion would be a total of 101.7 of their horse power, of which 2.48 is for the piston leakage, and 99.22 for that of the long valve and joints. Now correcting this for the excess of the reporters' estimates of mean pressure and leakage; again, for *their* unit of horse-power; and finally, for the proportions of *variable* and *constant* leakage, which by the experiments and investigation given in note 3, and discussed at page 36, I find to be as *two* to *one* instead of *four* to *one;* we have as the final, and I believe correct result, that the power for five miles of 9-inch main, at 18 inches exhaustion, (exclusive of "discharging power,") instead of 101.7 horses, would be but 49.7, of which 2.4 is for the piston leakage, and the remaining 47.3 for that of the valve and joints. Or if 21 inches be assumed as the working exhaustion, which I think not improbable on lines with those *steep inclines* which the "Atmospheric" principle admits of, or for increased loads; the power for the five miles, (still exclusive of the "discharging power") instead of 164 horses, which, according to the report, would be indispensable, would be but 69.3 horses.* These results, also those in the note at foot, are drawn from the reporters' experiments and statements, which however show a *total* leakage, about *four times* that deduced from the experiments of the 22d April, 1842, recorded at p. 82 of these "Observations." I am not aware of the mode of experimenting used by the reporters, therefore cannot trace the probable cause of this great difference; but it is not too much to assume, that what was done on the 22nd April, *without preparation*, may reasonably be expected on a line regularly worked, and of course regularly attended to; and consequently the above corrected "leakage discharging powers" may be expected to be reduced to one-fourth; that is, to prove in practice (not even 49.7 or 69.3, but only) about 13 and 18, instead of 101 and 164 horse-power; either, however, is a very important difference, when it is kept in mind that the power necessary to counteract the leakage, much more than the "discharging power," influences the distance at which the pumps may be placed apart; and, consequently, not only the amount of capital to be expended on engines, but also the future working expenses of a line of railway on the atmospheric principle. The following up of this part of the subject, however, more properly belongs to the third point noted for inquiry; but before proceeding further, it is right to say, and it must be kept in mind by those who have so far accompanied me, that these "leakage discharging powers" are altogether deduced from the actually existing apparatus at Wormwood Scrubs, and give little certainty as to the requirements in future constructions. One thing may be confidently asserted, that nothing at all so bad will again be worked; as any future apparatus must of necessity be in every respect much better.

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* With a velocity of 40 miles per hour, the discharging power for a 9-inch main, with 21 inches of exhaustion, would be 18.1 horses; making (with the 69.3 for leakage) the total engine power to be provided, 87.4 horses, instead of 200, which according to the reporters would be necessary. If the main were 18 inches in diameter, and the exhaustion as before, (21 inches,) also assuming that the piston leakage increased as the diameter, and that the valve leakage remains the same, the power required, according to my estimate, would by 145.0 horses, while by the reporters' mode of calculation, 312 would be necessary.

It will be observed that this strongly exemplifies the conclusion of the reporters, "that the economy of working increases at every point, as we "increase the scale of our operations." An increase of 60 per cent. in the power *quadruples the useful effect.*

The *second* subject which I have marked for investigation is, *the power absorbed or expended in producing any required exhaustion in the working main;* involving in this part of the enquiry, *the discharging power of the air-pump, and the waste of power by the leakage of the whole apparatus.*

The course pursued by the reporters for deducing the power expended, was to compute the number of strokes required to produce a given vacuum with a *perfect* air-pump; then to observe the number actually required; and the difference is set down as representing the power necessary to counteract leakage. It is not stated by the reporters, by what means the further extremity of the main was closed during their experiments; whether by the entrance valve, or by the travelling piston. If by the latter, the proceeding was not correct, inasmuch as it did not accord with the mode of working the Atmospheric Railway; in which, when *producing* the vacuum, the main would always be closed by the "entrance valve," and not by the travelling piston. And as this valve can without difficulty be made quite tight, their estimate of total leakage during exhaustion would, according to their own value of the "piston leakage," be 25 per cent. in excess, exclusive of all other causes of error; or by my value of the same, which I believe to be the correct one, (see note 3,) their deductions would be 50 per cent. above the truth. I thought it right to mention this, though in my comparisons I assume they used the entrance valve. Here again, the oversight of the imperfections of the pump vitiates the calculated results—slightly in the lower vacuums, but very seriously in the greater degrees of exhaustion. In Note 2, will be found the investigations from which have been calculated the same cases included in Table 1, introducing the omitted data; and in Table 3, I contrast these corrected results with those obtained by the reporters, completing the comparative view by calculating from their own theorems those cases not computed by them.

TABLE III.

No. as in Table I.	Vacuum Gauge in inches of Mercury.	Calculated number of Double Strokes to produce the Exhaustion.		
		By Reporters' Formula.	By Present Formula.	Number required more than given by Reporters' Formula, and in the report attributed to leakage.
1	11	19.2	20.9	1.7
2	12	21.5	23.5	2.
3	13	24	26.3	2.3
4	14	26.5	29.3	2.8
5	15	29.2	32.5	3.3
6	16	32.3	36.	3.7
7	17	35.3	39.9	4.6
8	18	38.7	44.2	5.5
9	19	42.3	49.	6.7
10	20	46.4	54.6	8.2
11	21	50.8	61.	10.2
12	22	55.8	68.7	12.9
13	23	61.5	78.2	16.7
14	23.5	64.6	85.3	20.7
15	24	68	90.9	22.9
16	25.75	83.3	133.	49.7
	(I)	(II)	(III)	(IV)

It will be recollected that the reporters' calculations, which I am now examining, are for the purpose of determining the *total* leakage of the Wormwood Scrubs experimental apparatus, preparatory to separating that total into two parts. FIRST, that which depends on the piston, and which is *constant*, whatever length of main be in use; and, SECOND, that of the long valve and joints, and which consequently *varies* with the length of the main. Now the determination of the respective amounts of these two leakages, I have already stated to be amongst the most important parts of the investigation ; as on it depends the amount of engine power to be provided, which of course affects the original expenditure of capital for construction, and the subsequent annual expenses for working.

This constitutes the third head of enquiry ; but before proceeding, it will be well to show how the deficiency of the reporters' theorem bears upon this question of constant and variable leakage.

The fourth column in Table 3, shows the number of strokes deficient, by the reporters' theorem, to produce the several degrees of exhaustion included in the tables. In the printed report, pages 8 and 9, are given the number of strokes *observed* as having been necessary to produce the degrees of exhaustion there stated. The same table (3,) shows, in column 2, the number which, according to the reporters' theorem, ought to have produced the same result ; the difference between the observed and calculated numbers is by them considered as the total leakage.

Again, in the report, page 7, it is stated that the engine at Wormwood Scrubs, when working at 29½ double strokes per minute, against a mean pressure of 5.41 lbs., was doing the work of twenty horses. It is true that subsequently it is stated the estimates of horse-power should be reduced in the proportion of 52 to 33; but as the greater numbers are left standing throughout the report, it is these I should use here.

With the data just stated, it is easy to ascertain by how many horse power the *apparent* total leakage was increased. The preceding data, together with the results, are given in the following

TABLE IV.

No. as in Table I.	Vacuum Gauge in Inches of Mercury.	Double Strokes to produce Vacuum.			Excess of observed number above estimated, and which is taken as leakage.		Excess of Reporters' estimated leakage. (The horse-power the same as used by Reporters.)	
		Observed Number. (Report p. 8)	Estimated Number.					
			By Reporters' Theorem.	By Present Theorem.	with Reporters' Theorem.	with Present Theorem.	Number of Double Strokes.	Equivalent Horse Power.
2	12	25.5	21.5	23.5	4.	2.	2.	1.2
4	14	34	26.5	29.5	7.5	4.7	2.8	1.8
5	15	37	29.2	32.5	7.8	4.5	3.3	2.1
6	16	42	32.3	36.	9.7	6.	3.7	2.4
8	18	58	38.7	44.2	19.3	13.8	5.5	3.4
9	19	69	42.3	49.	26.7	20.	6.7	4.
10	20	85.5	46.4	54.6	39.1	30.9	8.2	4.7
	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)

I now proceed to the *third head* of enquiry, namely, *the part of the whole leakage which, being due to the travelling piston, is constant, what-*

ever length of main be in use; and the part which is variable, being due to the long valve and joints, and consequently dependent on the length of main.

The method adopted for this purpose, as set forth in the report, was to observe the number of strokes of the air-pump required to maintain any given vacuum, when the long valve was of the whole length, and when it was reduced to three-fourths, and to one-half; and from these numbers is deduced, by inspection, the relative proportions of *constant* and *variable* leakage for half a mile of main. By this mode of proceeding, the reporters have arrived at the conclusion, that the leakage of the long valve is four times that of the piston: but the whole procedure is incorrect, not only in the *mode* of *experimenting*, but also in the *principle* of the *computations* founded thereon. The observations are not right, because it is obvious the whole leakage of the air-pump piston, be it much or little, is included with that of the long valve and travelling piston: and as to the principle of computation, the reporters overlook the fact, that as they diminished the space to be exhausted, they altered the ratio between this space and the pump, and of course varied its sake of comparison, using as the total amount of leakage that indicated by the reporters' experiments, during which the vacuum gauge fell at the rate of four inches per minute, (although in the experiments noted at page 82 of these observations, it only descended at the rate of 1.375 inches, showing but $\frac{1}{3.15}$, say one-third of their leakage,) and adding in a separate column the power which would be requisite with this lesser and I believe true amount,—we have, in contrast with the preceding extract, the following estimate :—

			With Reporters' Leakage.		With my Leakage.
½	mile	2.37 + 4.73 =	7.10	or	2.36
1	„	2.37 + 9.46 =	11.83	„	3.94
1½	„	2.37 + 13.19 =	15.56	„	5.19
2	„	2.37 + 18.92 =	21.29	„	7.1
2½	„	2.37 + 23.65 =	26.02	„	8.67
3	„	2.37 + 28.38 =	30.75	„	10.25

or the leakage power for three miles, instead of 62 horse-power, as given in the report, is but 31 or 10 horse-power, according as the reporters' or my observations of leakage may be realized; or, as before, extending this estimate, viz.—

			With Reporters' Leakage.		With my Leakage.
3½	miles	2.37 + 33.11 =	35.58	or	11.86
4	„	2.37 + 37.84 =	40.21	„	13.4

			With Reporters' Leakage.		With my Leakage.
4½	„	2.37 + 42.52	= 44.89	„	14.96
5	„	2.37 + 47.30	= 49.67	or	16.56
5½	„	2.37 + 52.03	= 54.40	„	18.13
6	„	2.37 + 55.76	= 58.13	„	19.37
6½	„	2.37 + 60.49	= 62.86	„	20.95

It appears that, even with the high amount of leakage during the reporters' experiments, 62 horse-power, instead of being requisite for *three miles*, is sufficient for no less than *six-and-a-half miles* ; or if the leakage, found during the experiments of April, be realized in practice, the "leakage discharging power" for 6½ miles of nine-inch main would be but 21 horse-power, instead of 131, as appears by the report.

When discussing the different units of horse-power, I stated the necessity of that point being properly understood and corrected ; as the unit adopted by the reporters was likely to produce an exceedingly erroneous impression, as to the amount of capital necessary to be expended in steam engines. Having just determined the "leakage discharging power" for six-and-a-half miles of nine-inch main, first, with the *greater* leakage and the unit used by the reporters ; secondly, with the same leakage and the *usual* unit;

and lastly, with my leakage and the *usual* unit, it will be instructive to convert these different horse-powers into money, at £40 each, which I consider a fair price for engine and air-pump.

	Value of Steam Engines to be provided		
	With the greater leakage during the Reporters' experiments,		With the lesser leakage of the 22nd April, and the usual unit.
	and the Reporters' unit.	and the usual unit.	
½ mile	£480	£280	£120
1 „	880	480	160
1½ „	1,280	640	200
2 „	1,680	840	280
2½ „	2,080	1,040	360
3 „	2,480	1,240	400
3½ „	2,880	1,440	480
4 „	3,280	1,600	520
4½ „	3,680	1,800	600
5 „	4,080	2,000	680
5½ „	4,480	2,160	720
6 „	4,880	2,320	760
6½ „	5,240	2,520	840

The "discharging" power for these 6½ miles, at 40 miles per hour, would be 33 of the reporters' horse-power, or 21 of the true *nominal* horse-power; therefore the *total* cost of engine-power for $6\frac{1}{2}$ miles in each of the above three cases, would be for the first, £6,560; for the second, £3,360; or for the third, only £1,680.

I may here observe, that the maximum pressure on the air-pump piston, is when the vacuum gauge stands at about 15.3 inches, and not at 18.9, as stated in the report at page 9. But this maximum, which is only of pressure or resistance, and not of exhaustion, is unimportant; as at that point, the pump is far from its maximum discharging power,* and the ratio of work done to power expended is decidedly disadvantageous. This is obvious from the following Table 5, which exhibits the quantity of air that would *appear* to be extracted by each single stroke of the pump, according to the reporters' mode of calculation; and, in the adjoining column, the quantity *actually* discharged. Both of these columns are calculated from the theorem (f) in Note 2. The same table also shows, in adjoining columns, the quantity of air, in cubic feet, removed at each single stroke, and the motive pressure in lbs. per square inch of the travelling piston, for each pound of mean pressure per square inch of the air-pump piston.

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* In reality, the maximum *discharging* power is at the first stroke, the quantities of air taken out at successive strokes being in a constantly decreasing ratio.

TABLE V.

No. as in preceding tables.	Inches of Mercury in Vacuum Gauge.	Estimated quantity of air extracted each single stroke of the pump.		Cubic feet of air extracted at each single stroke of the pump, for each pound of mean pressure per inch on the piston,		Motive pressure in lbs. per square inch of travelling piston for each lb. per inch of mean pressure on air-pump piston.	
		By Reporters' data	By Corrected data	On Reporters data	On Corrected data	On Reporters data	On Present data
1	11	9.22 cubic ft.	8.13 cubic ft.	2.12	1.71	1.27	1.16
2	12	8.73 „	7.61 „	1.90	1.56	1.30	1.23
3	13	8.25 „	7.09 „	1.69	1.41	1.33	1.29
4	14	7.76 „	6.57 „	1.54	1.29	1.39	1.37
5	15	7.28 „	6.05 „	1.40	1.18	1.44	1.46
6	16	6.79 „	5.53 „	1.27	1.08	1.5	1.56
7	17	6.31 „	5.01 „	1.16	0.99	1.56	1.68
8	18	5.82 „	4.49 „	1.06	0.91	1.64	1.82
9	19	5.34 „	3.97 „	0.97	0.83	1.72	1.99
10	20	4.85 „	3.45 „	0.88	0.76	1.82	2.21
11	21	4.37 „	2.93 „	0.81	0.69	1.94	2.49
12	22	3.88 „	2.41 „	0.73	0.63	2.08	2.88
13	23	3.39 „	1.89 „	0.67	0.57	2.26	3.48
14	23.5	3.11 „	1.57 „	0.62	0.54	2.36	4.01
15	24	2.91 „	1.37 „	0.60	0.51	2.48	4.51
16	25.75	2.06 „	0.46 „	0.50	0.41	3.1	11 7

It is here worth directing attention to a remarkable, and, at first sight, anomalous effect of the "Atmospheric" system, exhibited by the last section of the above table; namely, that *the greater the load moved* by the same pipe, or with the same load and pipe, the *greater the ascent* (within the ultimate power of the main,) *the less* the actual expenditure of *discharging* power *during* the transit over a given space, *at the same velocity.* A little consideration, however, shows that this is a necessary consequence of what has been already advanced; and is common both to the reporters' deductions and to mine, differing only in degree; for instance, (taking my deductions) on the one hand, the tractive force *increases* with the exhaustion, or with the equivalent pressure on the travelling piston; on the other hand, the mean resistance on the air-pump piston, which is the measure of discharging power to be employed, *decreases;* consequently, as the tractive force is *increased*, the discharging power is *diminished*: for example, supposing the barometer at 30 inches, and the equivalent weight of the atmosphere 15 lbs., with a nine inch main, the area of the travelling piston is 63.6 square inches. Now at 11 inches of exhaustion, the tractive force or pressure on this piston is 5½ lbs. per inch, or in the aggregate, 349.8 lbs. At this same degree of exhaustion it is seen, by Table 1, that the mean pressure on the air-pump piston is 4.75 lbs. per inch; its area being 1,104 square inches, and the length of the double stroke being 3.75 feet. If the load is to be moved with a velocity of 40 miles per hour, it will require 54 double strokes per minute to discharge the main at that rate, whatever be the amount of exhaustion; at 18 inches exhaustion, the tractive force is 9 lbs. per inch, or in all 572 lbs., and the mean pressure on the air-pump piston, 4.94 lbs.; at 21 inches vacuum, the tractive force is 667.8 lbs., and the air-pump piston pressure, 4.21 lbs. With these data, we obtain the following results:—

Exhaustion.		Tractive force on Piston.		Nominal Horse-power to discharge at forty miles per hour.
11 inches	....	349.8 lbs.	...	25.7
18 „	...	572.4 „	...	21.2
21 „	...	667.8 „	...	10.7

or the weight moved at the rate of 40 miles per hour, by a given *discharging* power, is, at 21 inches exhaustion, 4½ times as great as at 11 inches of vacuum. This result is of course exclusive of leakage, and of the power necessary to *produce* the previous exhaustion of the main; both of which will be greater with the greater vacuum. It is not necessary now to enter into a minute calculation on the subject; but I thought it worth noting, as it bears importantly on the question of gradients.

It would be tedious and not useful, to give the application of the corrected theorems to all the calculations in the printed report. The several formulæ I have used are stated in much detail in the Notes appended to these "Observations," so that any person feeling sufficient interest in the subject, can satisfy himself whether my statements are correct, and, without much difficulty or trouble, extend these calculations to almost every part of this highly important subject.

It was not my object to go through and examine all the numerical deductions of the report, neither is it my intention to follow the reporters through all the various statements deduced from their experiments; but having, as I have before stated, observed omissions which appeared to me materially to affect the conclusions arrived at, and having, with some trouble, satisfied myself that I was right; I felt it a duty for the sake of scientific truth, as well as of justice to what seems to me a most important invention,—and though last, not least, in justification of the part I have taken in urging the adoption of the atmospheric principle on the Dalkey line,—to promulgate my objections to a document which must be so influential. In doing so, it has been my anxious desire to avoid any expression which could, in the most remote degree, give offence. I hope I have succeeded; and from what I know of the party chiefly interested, I am quite certain my motives will be fairly appreciated.

I will now unite in a tabular form all the results distributed through the preceding five tables, so as to bring the whole comparison into one view, and then proceed to examine, as succinctly as possible, those other matters contained in the report, which I have designated matters of opinion only.

TABLE VI.

No. as in former Tables	Inches of Mercury in Vacuum Gauge.	MEAN PRESSURE on Air-pump piston in lbs. per square inch,			POWER to PRODUCE the Exhaustion in the half-mile of nine-inch Main at Wormwood Scrubs.								Quantity of Air extracted by each Stroke of the Air-pump.				POWER required to COUNTERACT the Leakage in the exhausted Main.		
					EXCLUSIVE of LEAKAGE during exhaustion, (Double Strokes,)			INCLUSIVE of LEAKAGE during exhaustion. (Double Strokes.)					Cubic Feet as given by		Cubic feet per Stroke for each lb of mean pressure per inch of Piston,		Double Strokes per Minute observed necessary to maintain the Exhaustion	Equivalent Nominal Horse Power.	
		By Reporters' Formula	By Present Formula	Difference by Reporters' Formula, resulting from their overlooking the imperfections of the Pump.	calculated by Reporters' Formula	calculated by corrected Formula	Deficiency of Reporters' calculations and in the report included in the leakage	Observed to be required	Excess of Observed over Calculated number and considered as Leakage		Excess of Reporters' estimate of Leakage.		Reporters' Formula	Corrected Formula	According to Reporters' Formula	According to Corrected Formula		By Reporters' Formula,	By Present Formula,
									By Reporters' Formula	By corrected Formula	Number of Double Strokes	Equivalent Horses' Power						with erroneous divisor of 33.000	with correct divisor of 52,000
1	11	4.34	4.75	— 0.41	19.2	20.9	1.7	—	—	—	—	—	9.22	8.13	2.12	1.71	—	—	—
2	12	4.59	4.87	— 0.28	21.5	23.5	2.	25.5	4.	2.	2.	1.2	8.73	7.61	1.90	1.56	—	—	—
3	13	4.87	5.02	— 0.25	24.	26.3	2.3	—	—	—	—	—	8.25	7.09	1.69	1.41	—	—	—
4	14	5.03	5.09	— 0.06	26.5	29.3	2.8	34.	7.5	4.7	2.8	1.8	7.76	6.57	1.54	1.29	—	—	—
5	15	5.19	5.13	+ 0.06	29.2	32.5	3.3	37.	7.8	4.5	3.3	2.1	7.28	6.05	1.40	1.18	—	—	—
6	16	5.33	5.12	+ 0.21	32.3	36.	3.7	42.	9.7	6.	3.7	2.4	6.79	5.53	1.27	1.08	16.	10.7	6.5
7	17	5.43	5.06	+ 0.37	35.3	39.9	4.6	—	—	—	—	—	6.31	5.01	1.16	0.99	—	—	—
8	18	5.49	4.94	+ 0.55	38.7	44.2	5.5	58.	19.3	13.8	5.5	3.4	5.82	4.49	1.06	0.91	18.	12.4	7.1
9	19	5.51	4.77	+ 0.74	42.3	49.	6.7	69.	26.7	20.	6.7	4.	5.34	3.97	0.97	0.83	—	—	—
10	20	5.49	4.53	+ 0.96	46.4	54.6	8.2	85.5	39.1	30.9	8.2	4.7	4.85	3.45	0.88	0.76	—	—	—
11	21	5.41	4.21	+ 1.20	50.8	61.0	10.2	—	—	—	—	—	4.37	2.93	0.81	0.69	29.5	20.	9.9
12	22	5.29	3.81	+ 1.48	55.8	68.7	12.9	—	—	—	—	—	3.88	2.41	0.73	0.63	—	—	—
13	23	5.09	3.30	+ 1.79	61.5	78.2	16.7	—	—	—	—	—	3.39	1.89	0.67	0.57	—	—	—
14	23.5	4.97	2.93	+ 2.04	64.6	85.3	20.7	—	—	—	—	—	3.11	1.57	0.62	0.54	42.	26.2	9.8
15	24	4.83	2.66	+ 2.17	68.	90.9	22.9	—	—	—	—	—	2.91	1.37	0.60	0.51	—	—	—
16	25.75	4.15	1.1	+ 3.05	83.3	133.	49.7	—	—	—	—	—	2.06	0.46	0.50	0.41	—	—	—

NOTE.—The Blanks in this Table are for cases for which there are not data given in the Report.

It is scarcely necessary to note that this Table applies exclusively *to the Apparatus at Wormwood Scrubs.*

Before passing on to the second division of these "Observations," it is right to offer a few remarks on some of the statements in the report, which do not properly fall under any of my classes.

At pages 10 and 11, it is stated, that certain observations were made with the view of ascertaining, "if possible, the working force which "different vacuums possessed of urging the train "forward, but (they) failed of obtaining on this "part of (their) inquiry any useful results, *the* "*engine not having sufficient power to preserve the* "*vacuum constant.*"

I should have drawn a different conclusion from these experiments; as I believe the falling of the gauge was due not to the insufficiency of the pump, but the reverse; and that its exhausting power was competent to produce on the travelling piston a motive pressure greater than the resistance of the load, the velocity of which was therefore rapidly increasing, and overrunning the pump; which must at all times occur to a greater or less extent, and is in fact inherent in the system; as the constant tendency of the train will be to approach its maximum velocity, which could only be reached by an *absolute* and *total* exhaustion of the main.

In the observations as to the leakage which are noted, (report, page 11,) the reporters found that with an exhaustion to 21 inches, and the whole long valve engaged, the gauge fell about four inches per minute. In the experiments noted in note 3 to these "Observations," it fell but about 1½ inches per minute, except with the shorter lengths of main, although the exhaustion was 23 inches; and in these experiments there was not any pains taken with either valve or piston, except to bring both as nearly as possible to their ordinary working state, by running the carriage several times along the line before beginning to note the leakage. The former indicates a leakage of about three times as much as the latter. I have already noticed this, and here only repeat, that what was effected without care in the latter experiments, may reasonably be expected on a line regularly worked and attended to.

The calculations at pp. 12 and 13 of the Report, as to the times of producing exhaustion in mains of various lengths and diameters, of course require the corrections of data on which I have already so long dwelt.

The reporters state, very justly, that in the wretched state of the line at Wormwood Scrubs, it is impossible to obtain experiments of any value for determining the friction of the apparatus. The time, however, is fast approaching, when this and all other matters affecting the working and economy of this most interesting and important invention, will be tested in the most satisfactory manner. I mean on the line now in progress between Kingstown and Dalkey, (which I confidently expect will be ready for working early in the ensuing spring,) where every possible facility will be given to the inquirer after the real value of the Atmospheric Railway.

I now come to the second class of observations —those which I have designated matters of opinion only. They are stated in the report, page 3, as follows :—

" The probable expence of constructing a rail-" way on this principle, and of supplying the " locomotive power."

" The relative economy in working such a line, " as compared with a railway worked by loco-" motive engines."

" The degree of safety which the atmospheric

" system affords, as compared with other loco-
" motive means."

Under the first of these heads,—economy of construction,—the inventors claim credit for a considerable saving in the weight of rails, in consequence of this system getting rid of the heavy locomotive engine; and that therefore the rails may be reduced from 75 or 80 lbs. per yard, (the weight now most frequently used,) to 30 lbs. per yard, or thereabouts; this is a serious item, amounting to about eight tons of rails, with the proportionate quantity of chairs, screws, &c. for each mile of single way. On the other hand, the reporters deny the full amount of this saving, but say, " They are ready to admit the " weight may be reduced to 56 lbs." This is clearly but matter of opinion on both sides; and in reference thereto, I will merely state my experience on the Dublin and Kingstown Railway. On this line the rails weigh but 45 lbs. per yard, and are fastened with the usual chairs; but these chairs, instead of being attached to cross sleepers or to stone blocks, are firmly screwed to longitudinal timbers, and the bearing is rendered continuous by slips of compressed wood, introduced between the top of the balk and the bottom of the rail. These rails, so laid, leave nothing to be desired, as to solidity and rigidity; in fact, there is scarcely any sensible deflection with the heavy coaches carrying forty persons, or even under the engines at full speed;* here then is sufficient proof that the rails may, at all events, be reduced to 45 lbs. per yard; and, contrary to the opinion advanced by the reporters, so satisfied are the Managers of the Dublin and Kingstown Railway on this point, that were there not a considerable stock of 45 lbs. rails on hand, the whole of the Dalkey line would have been laid with rails not exceeding 28 lbs. per yard. As it is, a portion will, for the purpose of experiment, be laid with rails not exceeding 20 lbs., which I am satisfied will prove abundantly sufficient.

This line, as I have before stated, will be in operation in a few months, and then experience will speedily present the most conclusive evidence as to the necessary strength of rails. Even now one thing is quite certain, that if rails of forty-five pounds per yard are found amply sufficient for locomotive engines of fourteen to fifteen tons, (nearly five tons on each driving wheel,) and moving themselves and their trains forward by the adhesion of their wheels to these rails; there can be no doubt that, even with the encreased velocity expected on the atmospheric line, *much lighter* rails will answer when there is no locomotive; and when the only duty of the rail is to sustain the incumbent weight of the passenger coaches, which do not now exceed one ton on each wheel; and which weight will, on the atmospheric system, be probably still further reduced.

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* By the experiments on the Dublin and Kingstown Railway, with a registering deflectometer, the deflection of the rails under a first class coach on six wheels, weighing with its load about five tons, is only .003 of an inch per lineal foot of rail.

The inventors also claim a very considerable amount of saving in the cost of construction, by the much steeper gradients which may be used on lines worked on the atmospheric principle, than on those worked by locomotive engines. The reporters call this a questionable item: their words are, "another questionable item is the "extremely reduced expense of cuttings and "embankments, it being assumed by the patentees, that not having to take the locomotive "engine up a plane, much steeper gradients may "be introduced than on the present lines:" and they go on to say, "that a great part of the "power of a heavy locomotive engine is expended in overcoming its own gravity and resistance, "in ascending steep planes, is certainly true; and

" it is equally true, that on the atmospheric prin- " ciple the whole additional force is exerted on " the load itself." This would seem to be an admission of all that is claimed ; but what is the conclusion drawn in the report ? " This is un- " questionably an advantage, but still we think " its importance greatly overrated."

I confess I am at a loss to conceive the grounds, on which this conclusion is drawn from the premises. It is true that in the next succeeding paragraph of the report, it is said, " the patentees propose to work steep inclines " by means of larger tubes ; but this would in- " volve the necessity of stopping the train at the " foot of such planes, and of having again to " overcome the inertia of the load, in both in- " stances causing a loss of time."

This is the only thing I can find like a reason for the almost anomalous conclusion just quoted, and certainly I cannot admit it to be at all sufficient ; assume for a moment, which however I altogether deny, that it was necessary to vary the size of the main on every ascent, and to stop the train at the foot thereof, for the purpose of changing the piston ; I should say the cases are very few indeed, in which the engineer, when laying out a line of railway, could not so arrange his plans, that these stopping places should be the most desirable for stations, and thus render the accommodation afforded to the public perfectly compatible with the efficient and economical working of the line. But I do not agree in supposing it necessary to change the dimensions of the main on every steep incline; table 5, in the previous part of these observations, shews that the less the exhaustion in the main, the greater the quantity of air extracted at each stroke of the pump in proportion to the power expended; or, in other words, that the less the exhaustion, (within proper limits), the diameter of the main being proportionately increased, the greater the economy of the system; and in this assertion I am fully borne out by the reporters' investigation (report, p. 12). Further, this reduction of vacuum does not materially affect the velocity of travelling, which is essentially dependent on the *discharging power* of the air pump. Such being the fact, an engineer, when looking out a line of railway, and starting with the knowledge that he is not restricted to levels or even to moderate gradients, would find few districts in which he could not be able to form the railway almost on the very surface of the country; for he would be at liberty to avail himself of almost any ascent; the only consequence of his doing so, being an increased expenditure of power, precisely in the ratio of the increased resistance. And if to this it be added, (which to all conversant with railways it does not require any arguments to prove) that when coaches alone are to be conveyed, curves of much shorter radii than would be practicable with the locomotive engine, are quite suitable; assuredly he could not have any difficulty in finding a line with the very minimum of cutting and enbankment, and consequently of bridges, viaducts, tunnels, walling, and in general of all works of art. On such a railway, let the main throughout be of large size, and the different degrees of inclination be worked by different degrees of exhaustion; and where an occasional ascent, steeper than could be conveniently managed by increased vacuum, does occur, let the engineer there place a main of enlarged size, and arrange a station at the foot; and I feel satisfied he will have effected the cheapest possible line of railway, whether for cost of construction, purchase of land, or for expense of working. This, however, is a part of the subject which more immediately and properly belongs to the civil engineer, well experienced in laying out lines of railway; and it has been so fully put forward in the letter addressed by my friend and colleague Mr. Pim, to the Right Honourable the President of the Board of Trade, (and which letter caused the reference to Sir Frederick Smith and Professor Barlow, and is printed in the appendix to their report) that I feel it unnecessary to enter at greater length into this part of the subject, or do more than express my firm conviction that very much indeed of the economy of construction claimed will be realized; and further, I am fully convinced that the atmospheric system will be the means of largely extending the advantages of railway communication to countries and to districts, the physical structure of which must totally debar them from these benefits, so long as the locomotive engine is the only motive power. One matter there is to which, although not mentioned by the reporters, I must allude. Few indeed are the situations in which a single line would not be adequate to all the traffic, if such could be worked without danger of collision. Now, in my view, the atmospheric system fully supplies the desideratum of safety, collision being physically impossible: let the civil engineer say what will be the further consequent economy of construction.

very short time, possibly about the same that would be occupied by the train at full speed in running over the length the engine has to exhaust. Now it occurs to me that, in such cases, it might be more economical to employ an engine of smaller dimensions, constructed on the best possible principles, say a Cornish pumping engine, if that be the best; to keep it uninterruptedly at work, lifting water into a reservoir, which could then be used at the proper intervals to drive a water wheel, with which to work the air pumps; if water were scarce, little fresh supply would be wanting, as the same water could be again and again pumped into the reservoir.

Other modes may occur; indeed I believe that at this time some individuals, quite competent to the task, are occupied in experiments and investigations having this very object in view, (the more economical exhaustion of the atmospheric main;) at all events, it is certain that if it once becomes an object, that object will not be long in being accomplished.

With respect to the velocity of travelling, or as it is ordinarily called, "the speed" of the train, there is a remarkable difference between the "Locomotive" and the "Atmospheric" systems. —— Wood, in his Practical Treatise on Railroads, 3rd edition, page 563, gives a table of the gross loads which an engine can move on a level railway at different "speeds," from 10 to 30 miles per hour. By this table we learn, that with the most powerful engine therein referred to, an increase of speed from 10 miles to 30 miles per hour, reduces the gross load from 352 tons to 35.66 tons; or, allowing for the *lesser time* during which the *greater speed* is exerted, a threefold speed destroys two-thirds of the useful effect. Pambour's investigations confirm this; and extending the formula to higher velocities, we find that at a speed under 50 miles an hour, the engine experimented on by Wood can only move itself and tender. Variations in the proportions, or power of the engines, will place this point of *no-useful-effect* at higher speeds, but the law of diminution still continues in operation.

Now, with the "Atmospheric" system nothing of this kind obtains; increased speed does not in any degree diminish the motive pressure on the travelling piston; and the velocity with which air rushes into an exhausted or partially exhausted receiver, while it vastly exceeds any probable working "speed," is totally independent of the "discharging power" by which the advance of the train is regulated. Now the discharging power being that necessary to remove the rarefied air from the main, it is obvious that an air-pump of *double area* will remove *double the quantity* in the same time, and so for any other multiple area; but the theorem for mean pressures on the air-pump piston shows that, for the same degree of rarefaction, the mean resistance throughout the stroke is directly as the area of the piston; therefore, the "discharging power" is as the speed; but the greater the speed, the less the time in passing over a given distance; consequently, the total amount of discharging power, expended *during the transit* of a given load over a given distance, is the same, whatever the speed.

This conclusion does not allow for the retarding force of the air, which will of course diminish the actual speed; but we are not in possession of data from which to determine its effect; nor is it material for the present comparison, as it will be the same on both systems.

On the other hand, a certain and no inconsiderable degree of saving will be the consequence of increased speed on the atmospheric railway. I refer to leakage, which, whether during production of vacuum or "discharge" of the main, and even with the lowest of the previous estimates as to its total amount, is still considerable; but it is sufficiently obvious, that with the same degree of rarefaction, this leakage will be proportioned to the time; consequently, the greater the speed, the less the loss from this cause.

I am therefore justified in stating, that there is not any loss of power, either in a mechanical or economic point of view, in increasing the speed of transit on the atmospheric railway; consequently, any *desirable* rate of travelling may be attained without disadvantage.

There remains but one other matter to which I think it necessary to advert; but that one is, in my judgment, of such paramount importance, that more than any other it characterizes the atmospheric system; I mean the safety of the passengers; not merely relatively to other modes of transit, but the highest attainable degree of absolute safety.

Notwithstanding that a few fearful casualties have occurred, I believe every candid and dispassionate person will unhesitatingly admit railway travelling to be, of all others, the most free from danger; and that railway casualties bear an exceedingly small proportion indeed to those of any other, even the very best mode of locomotion.

Now, what the locomotive system is, in point of safety to the older modes of travelling, I believe the atmospheric to be to the locomotive: in a word, as free from hazard as it is possible for any human contrivance to be. What elements of danger are there?—collision is impossible, all recognised causes of fracture of parts are almost altogether absent; in short, although seeking for causes of danger on one of the most crowded railways in the empire, with a view to their prevention, has for some years been one of my most anxious avocations, I cannot see where danger is to come from. In speaking on this subject, the reporters say, "on railways, it is "a great element of safety that the source of "power is present with the train, and may be "almost instantly turned off if any necessity "shows itself for the stopping." The presence of the engine, it is too well known, has not always proved a source of safety, as no inconsiderable portion of the very worst of railway casualties have been solely occasioned by it; the latter part of the sentence is generally true, but in this respect there is no difference between the locomotive and the atmospheric systems; or if there be, it is in my opinion in favour of the latter, inasmuch as the means of turning off the power are still more certain. The regulator or steam cock of a locomotive engine may stick fast, so that the engine-man cannot move it; this I have more than once known to be the case. But, there are abundance of contrivances in daily use, any one of which is adequate for uniting the travelling piston to the train, and in which no difficulty of separation, nor apprehension of any derangement, can possibly exist. Besides, even were this not the case, this separation or casting off is not the only means at the command of the conductor; in common with the locomotive train, he has the brake; and in addition, he has the power of instantly opening a communication between the exhausted main and the atmosphere. This latter, of course, is not so immediate in its action as shutting off the steam in a locomotive; but combined with the brake (which, from the much less weight and momentum of the atmospheric train, I know by frequent trials, even at full speed, and with the full motive pressure in operation, to be much more effective than with a locomotive engine) I believe it practicable to bring to rest a train moved by atmospheric pressure, in as short a space as is consistent with the materials of the carriages holding together.

I have now brought these "Observations" to a close. I am aware there still remain parts of the report to which I might have referred; but enough has been said for my purpose, which was to prove that the labour of the reporters, valuable as it has been, is not in all respects correct; and that consequently they have been led to conclusions, as to the economy and efficiency of this most interesting invention, considerably short of what may with confidence be looked for. If, as is possible, in the latter section of these "Observations," when dealing with those parts of the subject, which in the present stage of the invention are purely matters of opinion, I have occasionally expressed myself rather as an advocate for, than as an enquirer into the system; I can only say I have no personal interest, present or prospective, in the invention, and that any warmth of expression, if such there be, solely results from the strength of my conviction, and a desire to place on record the grounds on which, having once satisfied my own mind on the subject, I have, in common with my colleague Mr. Pim, and so far as was in my power, not ceased to urge, in all honesty of purpose, on the

Directors of the Dublin and Kingstown Railway, the adoption of this principle of locomotion for the Dalkey line; confident that thereby they would largely advance the interest and prosperity of the company over which they preside; and in so doing, bring to the test of experience an invention, the beneficial results of which to Ireland, and indeed to most other countries, I believe it hardly possible too highly to appreciate or too warmly to anticipate.

NOTES.

NOTES.

Note 1, *referred to from page* 24.

When the air-pump piston is at the beginning of a stroke, the whole space within the pump, including valve recesses and clearance, (as it is technically called) is 15.411 cubic feet; at the termination of a stroke, the piston has passed through 14.373 cubic feet, leaving a space of 1.0385 cubic feet through which it has not passed, and from which of course the air has not been expelled.

Calling these two latter quantities B and $B\lambda$, we have

$$B(1+\lambda) = 15.411 \text{ cubic feet,}$$

and

$$B\lambda = 1.0385 \quad ,,$$

from whence we obtain

$$\lambda = 0.0723$$

The published meteorological tables show that on the 22nd April, the day on which certain experiments, hereafter detailed, were made at Wormwood Scrubs, the mean height of the barometer at London was 30 inches very nearly, and by indicator diagrams taken at the same time, it is shewn that the discharge valve of the air-pump, as the mean of eight experiments, required a force equal to 1.263 inches of mercury to open it. Calling this force δ, we have as the density of the air within the pump barrel, necessary to open the discharge valve against the atmosphere, $1 + \delta$.

The ratio of the space within the pump, at the end of each stroke filled with air of the density $1 + \delta$, to the whole space within the pump-barrel, is

$$\frac{\lambda}{1 + \lambda} = \frac{0.0723}{1.0723} = 0.0674$$

Let P be the density of the air in the working main, at the commencement of any stroke of the pump, that is

$$P = \frac{\text{Barometer} - \text{Vacuum Gauge}}{\text{Barometer}}$$

Suppose the piston at the bottom of the air-pump barrel at the termination of any stroke, and calling the density of the external air = unity, the space $B\lambda$ behind or below the piston is full of air of the density $1 + \delta$, because it has opened the discharge valve against the pressure of the atmosphere.

The connecting valve between the working main or receiver, and the air-pump barrel, also requires some force to open it. I omitted to ascertain the actual value of this force, but as the connecting valve does not in any respect differ from the discharge valve, I assume it offers the same resistance. Call the density necessary to overcome this resistance δ', consequently the space $B(1 + \lambda)$ above or in front of the piston is full of air of the density $P - \delta'$, because the connecting valve closes as soon as the difference of the pressures on each side $= \delta'$

As the air-pump piston is drawn up, the air above is condensed till it acquires sufficient elasticity to open the discharge valve, that is, till its density becomes $1 + \delta$. The air below or behind the piston is at the same time rarefied, until the connecting valve opens, which occurs when its density is reduced to $P - \delta'$.

Call the length of the stroke of the air-pump L, of that portion of the stroke which has been made when the discharge valve opens l', and of the portion made when the connecting valve opens l''. Also let l be any indeterminate part of the stroke.

Then the resistance to the motion of the piston, from the condensation of the air in front of it at any part of the stroke, l, is

$$\frac{(P-\delta')\,(1+\lambda)\,L}{L\,(1+\lambda)-l} \text{ .... (a)}$$

This resistance goes on increasing from the beginning of the stroke when $l = o$ until the discharge valve opens, or $l = l'$, at which time the value of the above equation (a) is $1 + \delta$, from whence

$$l' = L\,\frac{(1+\lambda)}{(1+\delta)}\,(1+\delta+\delta'-P) \text{ ...(b)}$$

after which the pressure above the piston for the remainder of the stroke $= 1 + \delta$

The sum of these resistances would be the total resistance to the motion of the piston, if there was a perfect vacuum below it, or if $\lambda = o$; but as this is not the case, in the experiments and apparatus under consideration, this resistance from above is diminished or counteracted by the elasticity of the air below, which fills the space $L\,\lambda$, and is, at the beginning of the stroke, of the density $1 + \delta$

As the piston advances, the space $L\,\lambda$ is enlarged, and the contained air expanding, its elasticity is of course diminished until reduced to $P - \delta'$, when the connecting valve opens, and the air from the main flows in.

The expression for the density or elasticity of this air at any portion of the stroke l less than l'' is

$$\frac{L\lambda\ (1 + \delta)}{L\lambda + l} \text{ .... (c)}$$

This elasticity, as before stated, decreases from the commencement of the stroke when $l = o$, till the connecting valve opens, or when $l = l''$, which occurs when the value of the above expression (c) becomes $P - \delta'$, or when

$$l = l'' = L\,\lambda\ \frac{(1 + \delta + \delta' - P)}{(P - \delta')} \text{ ....(d)}$$

after which the pressure from below may be taken as uniform for the remainder of the stroke, and $= P - \delta'$

It is here obvious that when P is such that $\frac{l''}{L} = 1$, the connecting valve will no longer open and exhaustion must cease, which happens when

$$P = \delta' + \frac{\lambda\,(1 + \delta)}{(1 + \lambda)} \text{ .... (e)}$$

or in the Wormwood Scrubs pump, when the vacuum gauge stands at 26.64 inches of mercury.*

---

* The vacuum gauge, I am informed, has repeatedly been raised to 27 inches; the difference between this and my deduction is easily accounted for, by variations in the force necessary to open the discharge valve, which I see by the indicator diagrams before referred to, varied from 2.63 inches to 0.65 inches. I have used the mean of eight diagrams as my value of δ.

It is also manifest that l'', the inactive portion of the stroke, is greater, the less P is.

Were the air pump perfectly free from leakage, there would be a small decrease of this elasticity $P - \delta'$, in the ratio of the space described by the piston to the whole space to be exhausted; but as this ratio is small, and as the pump is not free from leakage, this may be assumed to counteract the former, and the elasticity $P - \delta'$ be taken as uniform from l'' to L.

The effect of the elasticity of the air behind the piston, being antagonist to that of the condensation of the air before it, the whole effective resistance is obtained by deducting the sum of the former from that of the latter.

The sum of each of these resistances having been found within the proper limits by the ordinary processes of integration, the following is the final expression for the resistance of the air-pump piston throughout any one stroke:—

$$L\left\{P - \delta' + \lambda(P - 1 - \delta - \delta')\right\} \mathit{hyp\ log} \frac{(1 + \delta)}{(P - \delta')} \ldots (f)$$

or dividing by L and multiplying by the pressure of the external atmosphere, (in the present experiments 15lbs.) we obtain the mean pressures in lbs. per square inch on the piston, which are inserted in Tab. I.

This pressure is a maximum when

$$1 - hyp\ log(1+\delta) + hyp\ log(P-\delta') = \frac{\lambda\,(1+\delta)}{(1+\lambda)(P-\delta')}$$

which occurs when

$$P = 0.49 \text{ nearly,}$$

or when the gauge stands at about 15.3 inches.

In the above formula (f) when δ, δ', and λ are each $= o$, it becomes

$$hyp\ log\left(\frac{1}{P}\right) P$$

which is identical with the formula for mean pressure, given by the reporters at page 7 of the printed report, in which the equivalent of P is $\frac{30 - h}{2}$ and that of $\frac{1}{P}$ is $\frac{30}{30 - h}$ but Table I. shows the importance of the quantities omitted by the reporters.

Note 2, *referred to from page* 31.

Let the capacity of the receiver or main $= S$, and continue the notation used in note 1.

Then to determine the quantity of air of atmospheric density abstracted by any one stroke of the pump.

The density of the air in the main, at the commencement of the stroke, being P, the quantity is of course S P.

Let x represent the quantity of air which passes from the main into the pump barrel during the stroke. The quantity of air in the pump barrel after the preceding stroke is, as before stated, $B\lambda\,(1 + \delta)$. At the end of the stroke the quantity x has flowed in, and the barrel now contains $B\lambda\,(1 + \delta) + x$, and its density is

$$\frac{B\lambda\,(1 + \delta) + x}{B\,(1 + \lambda)}$$

At the beginning of the stroke the quantity of air in the main was S P; at the end it has become $SP - x$. Its density at the commencement was P, at the termination it is $P - \frac{x}{S}$, and is greater than that of the air in the barrel by δ', the force necessary to open the connecting valve; consequently, (the expression for the elasticity of the air being the same as that for its density, the temperature remaining unchanged,) we have the following equation from which to find the value of x,

$$P - \frac{x}{S} = \frac{B\lambda\,(1 + \delta) + x}{B\,(1 + \lambda)} + \delta'$$

from which we obtain

$$P - \delta' - \frac{\lambda}{1 + \lambda}(1 + \delta) = x\left\{\frac{1}{B\,(1 + \lambda)} + \frac{1}{S}\right\}$$

but $\delta' + \frac{\lambda}{1 + \lambda}(1 + \delta)$ has already been found to be the value of P when $\frac{l''}{L} = 1$.

call $$\delta' + \frac{\lambda}{1 + \lambda}(1 + \delta) = a$$

Let r be the ratio between S, the space in the main, and $S + B\,(1 + \lambda)$ the sum of the spaces in the main and pump barrel; or,

$$\frac{r}{1} = \frac{S}{S + B\,(1 + \lambda)}$$

call $$\frac{1}{B\,(1 + \lambda)} + \frac{1}{S} = \frac{1}{Br.\,(1 + \lambda)}$$ then

$$x = (P - a)\,r\,B\,(1 + \lambda) \;\ldots\ldots\ldots\; (g)$$

Whence we see that when $P = a$, $x = o$, and the pump ceases to exhaust; but a or its equivalent $\delta' + \frac{\lambda}{1 + \lambda}(1 + \delta)$ we have seen is the value of P when the whole stroke is inoperative; consequently, the limit of exhaustion in the Wormwood Scrubs pump, is when P + 0.113, or when the vacuum guage stands at 26.64 inches.

The expression for the quantity of air exhausted at any one stroke $(P - a)\,r\,B\,(1 + \lambda)$

shews how the discharging power of the pump is affected by its imperfections. The quantity discharged is as $P - a$; while in a perfect instrument, to which alone the reporters' formula applies, it is as P. Thus, if the gauge stands at 18 inches or $P = 0.4$, then $P - a = 0.2876$, or the discharge is little more than two-thirds what it would be with a perfect pump. If the gauge be at 22 inches, or $P = 0.27$, then $P - a$ only $= 0.1576$, or little more than one-half, while the process of deducing the discharging power used by the reporters, would assign the whole of this diminution of effect to leakage, which in the one case would be set down as nearly one-third, and in the others as almost one-half of the whole power of the pump.

We have also ascertained the limits of exhausting power of the pump, or that $x = o$, when

$$P = a = \delta' + \frac{\lambda}{1 + \lambda}(1 + \delta) \quad \ldots\ldots \text{(h)}$$

Our next step is to determine the number of strokes required to produce any given amount of exhaustion in the main, that is, any given value of P.

We have seen that the change of density produced in the main by any one stroke of the air pump $= \frac{x}{S}$ Call this density after the n^{th} stroke,

P_n and so on. From the expression for x we have

$$P_n = P_{n-1} \times r + a(1 - r)$$
$$P_{n+1} = P_n \times r + a(1 - r)$$

whence

$$P_n - P_{n+1} = (P_{n-1} - P_n)\, r$$

or the differences of density in successive strokes form a geometrical series, whose common ratio is r. As we begin with atmospheric density or $P = 1$, the first difference $= (1 - r)(1 - a)$ and the $n - 1$ terms is

$$\frac{(1 - r)(1 - a)(1 - r^n)}{1 - r}$$

and subtracting this from unity

$$P_n = r^n(1 - a) + a$$

then the number of strokes n required to produce a given density P_n is

$$n = \frac{log\left(\frac{P_n - a}{1 - a}\right)}{log \quad r} \text{ .... } (i)$$

The Reporters' formula is

$$n = \frac{log\ P_n}{log\ r}$$

For the value of r.

From accurate measurements made for the purpose of the present enquiry, I find that the cubic contents of the main is 1165.56 feet; of the branch connecting this main with the air-pump, and which necessarily forms part of the general space to be exhausted, 40.90 feet. The total content of the pump above the piston, as already stated, is 15.41 feet, consequently

$$r = \frac{1165.56 + 40.90}{1165.56 + 40.90 + 15.41} = \left.\frac{1206.46}{1221.87} = \frac{78}{79}\right\} \text{nearly}$$

the value of r in the report, $\frac{88}{85}$, the difference being due to the omission of the waste space in the air-pump so often referred to.

With the theorems (f) (g) (h) now deduced, tables 3 and 5 have been computed.

Note 3, *referred to from page* 36.

SEPARATION OF VARIABLE FROM CONSTANT LEAKAGE.

The method I have adopted for this purpose, is to note the rate of reduction of vacuum by leakage, by observing the falling of the vacuum guage in each successive minute, commencing the observations for different lengths of pipe at a high degree of exhaustion.

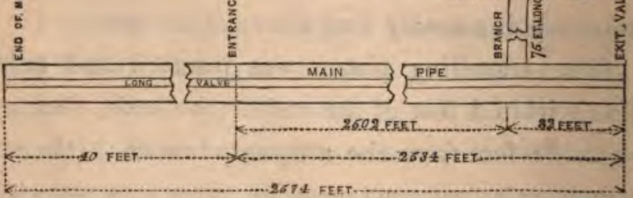
If we suppose air to leak into a partially exhausted receiver, through apertures represented by the quantity O^{feet}, for the time t^{s}, then from the expression for the velocity $V' = V \times \sqrt{1 - P}$ we easily deduce the following equation,

$$O = \frac{2\,S}{V\,t}\left(\sqrt{1 - P} - \sqrt{1 - p}\right) \ldots\ldots \text{(k)}$$

p being the density in the vessel at the end of the time t, and V the velocity with which air enters a vacuum temperature, being 55° = 1340 feet per second; the other symbols as before. From this, O can be computed. Now O is composed of two parts, one proportionate to the length of valve, the other constant; two trials with different lengths of valve should enable us to separate them, but it is better to have as many as possible, and combine them in the usual way to obtain a mean result. As the printed report contains but a single observation of the kind required, the necessary experiments were instituted on the 22nd April, 1842, the temperature being nearly that above mentioned.

The travelling piston was inserted and held fast within 4 feet of the end of the main, that is, at 2.538 feet from the air-pump branch; (*the entrance valve was not used in these experiments,*) the exhaustion was then carried to about 23 inches, the pump was stopped, and the descent of the column of mercury noted at the end of each minute. The same was repeated eight times, the piston being each time moved forward about one-eighth part of the whole distance between the first station and the air-pump. A ninth trial was made, with the piston close to the branch; but in this case, the air-pump itself bore so large a proportion to the space to be exhausted, and was so irregularly connected therewith by the leakage of its valves, and the column of mercury descended so rapidly, that but two uncertain observations could be made. I have therefore not included it.

For convenience of computation I tabulate the conditions and observations of each of these trials. I also think it desirable to give a diagram of the main and branch pipes, so as to prevent any misunderstanding.



By this sketch it is seen that the entire length of long valve engaged in the experiments is 2570 feet; that is, from 4 feet within the ends of the main to the exit valve. The main consists of several separate lengths, each 9 feet, united by socket joints. In each succeeding experiment the travelling piston was moved forward 36 of these lengths, or 317.25 feet, (the difference, 6.75 feet, being the aggregate length of the sockets,) thereby diminishing the total capacity S by 143 cubic feet, and the long valve by 0.1234 of its whole length. The following table exhibits the data and observations :—

	EXPERIMENT.							
	1	2	3	4	5	6	7	8
Mercury in Gauge raised to	23 ins.	23 ins.	22 ins.	21 ins.	20 ins.	22 ins.	22 ins.	24 ins.
Cubic contents of Main and Branch, (value of S)	1204.46	1063.46	920.46	777.46	634.46	491.46	348.46	205,46
Proportion of long valve	1.—	.8766	.7531	.6298	.5064	.3830	.2596	.1362
	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.
Descent of Mercury during 1st minute	1½	1⅜	1½	1½	1¾	1⅞	2	3
2nd „	1½	1⅜	1¾	1½	1¾	2⅛	2¼	3¼
3rd „	1⅜	1¼	1½	1¾	1⅞	1⅞	2¼	3
4th „	1⅜	1¼	1⅝	1½	1⅞	1⅜	2⅛	3
5th „	1½	1¼	1⅝	1½	—	2⅜	—	—
6th „	1¼	1¼	1½	1½	—	—	—	—
7th „	1⅜	1¼	—	—	—	—	—	—
8th „	1⅛	1¼	—	—	—	—	—	—
Mean descent ⅌ minute	1.375	1.281	1.583	1.542	1.812	1.925	2.156	3 063

From these observed results I calculate by the preceding theorem (*i*), the separate values of O for each experiment; but, as before stated, in each case O consists of two parts, the constant and the variable leakage; calling the former z and the latter y, we have

$O_1 = z + 1.0000\,y = 0.00091763$ square feet.
$O_2 = z + 0.8766\,y = 0.00073989$ „ „
$O_3 = z + 0.7532\,y = 0.00080649$ „ „
$O_4 = z + 0.6298\,y = 0.00067952$ „ „
$O_5 = z + 0.5064\,y = 0.00064939$ „ „
$O_6 = z + 0.3830\,y = 0.00052347$ „ „
$O_7 = z + 0.2596\,y = 0.00040879$ „ „
$O_8 = z + 0.1362\,y = 0.00034319$ „ „

Grouping these so that the co-efficient of y may be relatively as large as possible in one set, and as little as possible in the other, we have

$$z + 0.8149\,y = 0.00078588$$

and

$$z + 0.3213\,y = 0.00048121$$

from whence we obtain

$$z = 0.00030039$$
$$y = 0.00061724$$

or

$$z : y :: 1 : 2.0548$$

say

$$:: 1 : 2$$

instead of

$$:: 1 : 4$$

as the reporters made them.

THE END.

atmos, R.

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